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Statistical Transients in Transmission Systems

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(Abstract) A statistical study for the switching processes in transmission and distribution electric systems, including earth return effect, is presented. The frequency dependence for the parameters of the studied system with a homogenous earth return is included as well as the random values for the closing angle of circuit breakers are taken statistically. Expressions for voltage and currents in modal coordinates are deduced. The overall presence number of transients and the average over-voltage are computed for random angles of switching. The effect of length of lines at different voltage levels is evaluated. A profile for the boundaries of either transmission or distribution network is discussed and analyzed. The comparison in the analysis accounts the effect of transposition for the non-transposed lines. The results are considered for the standard values of voltage level, which is varied from 3 kv up to 500 kv.

Keywords: Modal Coordinates – Compensation; Un-transposition; Transmission; Transients; Distribution.

List of symbols

Symbol	meaning	**symbol**	meaning
[Z]	Impedance matrix	$\mathbf{R_c}$	Conductor resistance
[R]	Resistance matrix	**[T]**	Transformation matrix
N_t	Number of transients points inside the time length	**A , B**	Elements of the transformation matrix (A= 1.2 , B= 1.8)
$\Sigma (Z_l)_T$	Sum of the impedance of lines in the transmission system	λ_1 , λ_2 & λ_3	Roots of the characteristic equation for the propagation coefficients variable
$\mathbf{R_g}$	Ground resistance	$\mathbf{Z_{1,2}}$	Characteristic impedance
$\mathbf{L_s}$	Self inductance of a line	$\mathbf{Z_c}$	Surge impedance
$\mathbf{L_m}$	Mutual inductance of the line	$V(x), I(x)$	Voltage and Current at a point x
γ , γ_1 & γ_2	Propagation coefficients of the line	$V(l), I(l)$	Voltage and current at the receiving end
$\mathbf{C_m}$	Mutual capacitance of a line	$\mathbf{C_s}$	Self capacitance of a line
ω	Angular frequency	**[X]**	Inductive impedance matrix
x	Distance on the line measured from the sending end	$(\alpha) ,(\beta), (0)$	The three wave mode coordinates
$(N_t)_D$	transient number for the distribution system	E , L_{supply}	Voltage and current at the receiving end
$\mathbf{V_o}$	Average over-voltage	σ	Standard deviation
L	Line length	$\mathbf{T_o}$	Time interval duration
DTR	Distribution to transmission ratio	$\Sigma(Z_l)_D$	Sum of the impedance of lines in the distribution system
$(N_t)_T$	transient number for the transmission system	K	Total Number of points inside the time length
TN_G	General transient number	TN	*Transient Number*
GR	General ratio		

1 . INTRODUCTION

Transients are used as disturbance sources for illustration. The proposed first method utilises harmonic voltages and wavelet coefficients as **PQ** features. An enhanced genetic algorithm is proposed for solving the modified K-means clustering to place **PQ** measurement monitors. This also, would be presented with the transients because the assymetry should be presented [1]. The transient processes in a power network may lead to damage for the operation either partially or completely in spite of it is related to the operation system itself. Otherwise, the switching transients may be internal or external and consequently, the study of such item must be significant to bring the system to the safe and suitable zone. Also, the transient phenomena can be occurred either for a long time length such as electromechanical type or for a short time as the electromagnetic switching processes [2]. This subject takes the action with both transmission and distribution systems so that it may be investigated more and more in future. The impedance **Z** of a symmetrical line as a function of its parameters (conductor resistance $\mathbf{R_c}$ and ground $\mathbf{R_g}$ as well as self inductance **L** and mutual **M** may be formulated as given by equation 1 in appendix.

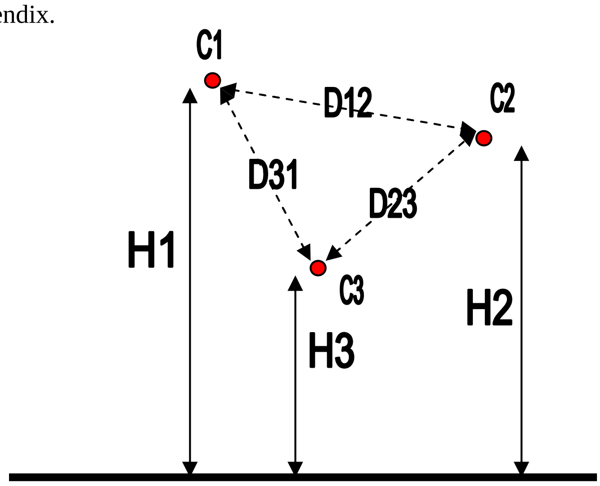


Fig. 1: The geometry of conductors

There are some different approaches tried to regulate the parameters of a power system generally [3 - 4]. Others went to transmission lines or even to change the concept of transmission but the final practical solution requires more effort [5 -7]. Also, there are new types of lines such as flexible alternating current **AC** transmission systems **FACTS** [8, 9]. The switching transients depends to a great extend on the parameters of the system where the ground return effect plays an important role. The earth will be considered as a homogenous for simplicity and so, the Carson concept would be applied [10]. Otherwise, the capacitance is taken as a constant without any ground effect while the frequency dependent parameters are introduced. The self capacitance will be $\mathbf{C_s}$ and the mutual will be $\mathbf{C_m}$. Hence, this paper studies both systems transmission (500, 330, 220, 110 kV) and distribution (35, 10, 6 kV) as sample for any network in order to conclude the statistical performance for a system under the transient conditions. Hence, the random five values for the switching angle are applied to present the general case of switching transients [10]. The overall geometry of phases on standard towers, as shown in Fig. 1, is listed in Table 1 [11]. It should be mentioned that the transmission lines of high-voltage networks are protected against lightning strikes and internal overvoltages with the use of overhead ground wires and surge arresters. The appropriate modelling of a power system's components is a significant issue, in order to obtain reliable theoretical simulation results for the lightning performance of the line that will be used in the design of a new line or the improvement of an existing one [7, 12, 13].

It is required to illustrate the objective aim of the study where certain national power system cannot be identical to the other. Then, the determination of a general performance for all networks through the investigation of any one may take us away from the actual condition in the site. However, the transient characteristics depend on mainly the parameters of a system where their values can be evaluated through the geometry of phases. This means that the geometry allocation of phases will reflect the overall behavior in the domain of electromagnetic transients. Therefore, the classes of distribution and transmission can be taken as the gate to solve such problem and consequently its generalization may be implemented.

Since shunt capacitors are installed normally in large distribution systems and so, many critical nodes may be appeared. Also, the power harmonics and capacitor switching

Table 1, a: Dimensions of considered Towers (m)

Type	Outdoor		Indoor
Tower	Metal	Wood	Metal
kV	500 330 220 110 35 6-10	220 110 35 6-10	220 150 110 35 20/10 6/3
H1	20–19 16-30 18.5-30 15.5-18 12-17.5 9-8.9	12 9 11 9.5	5.3 3.5 2.3 0.93 0.58/0.38 0.29/0.25
H2	20–19 16-23 14-24 12.5-15 9-14.5 9-7.6	12 9 11 8.75	3.5 2.3 1.5 0.61 0.38/0.25 0.19/0.35
H3	20–19 16-23 14-18 12.5-12 9-11.5 9-7.6	12 9 11 8	1.7 1.1 0.7 0.29 0.18/0.12 0.09/0.065

Table 1, b: Dimensions (m) for the considered towers in the research

Type	Outdoor		Indoor
Tower	Metal	Wood	Metal
kV	500	220	220
	330	110	150
	220	35	110
	110	6-10	35
	35		20/10
	6-10		6/3
D12	11-13	5	1.8
	8.5-9.4	4	1.2
	6.8-7.1	3	0.8
	4.24-3.27	1.5	0.32
	3-3.08		0.2/0.13
	1.5		0.1/0.07
D23	11-13	5	1.8
	8.-8.6	4	1.2
	6-6.86	3	0.8
	5.5-3.27	1.5	0.32
	3-3.06		0.2/0.13
	1.5		0.1/0.07
D31	22-26	10	3.6
	16-7.5	8	2.4
	6.8-13	6	1.6
	4.24-6	1.5	0.64
	4.24-6		0.4/0.26
	3-1.5		0.2/0.14

This projects the idea of the presented work according to the evaluation of the boundaries for the profile of switching transients in power system. The investigation may be tailored into two steps. The first will be for each system (Distribution or transmission) while the second deals with the statistical variation in length or voltage or even in the percentage content of a system relative to the other inside the network. After that, the general profile can be computed for different values of content ration (Distribution to transmission ratio). Otherwise, the data cannot be based on the population readings so that the statistical sampling processes must be inserted.

The main equations of voltage and current at a point x of a line are given in a matrix form of equation 2 in the appendix. Also, the deduced Voltage at a point x with the help of Sylvester theorem [12] may be found as shown in appendix (equation 3). Otherwise, the current can be derived as in equation 4 (Appendix). The replacement of the matrix of propagation coefficient by a multi term equation according to the rule of Sylvester will simplify the derived formula for the propagation coefficient (See equation 5 in the appendix. Then, the formula of the propagation coefficient appears to be in the form of equation 6 (Appendix).

2 . MODAL COORDINATES {α, β, 0}

This result will be more complicated for the non-transposed lines in the **LAPLACIAN** domain and so the final formula can be solved in the wave mode coordinates. On the other hand, the distribution power networks plays an important role in the processes of operation and many papers were analyzed this system as in [4]. The modal technique gives the simplicity for the solution of such problems in the complex plane so that the main parameters of the deduced equation (6) may be applied in each of the modes of the analysis.

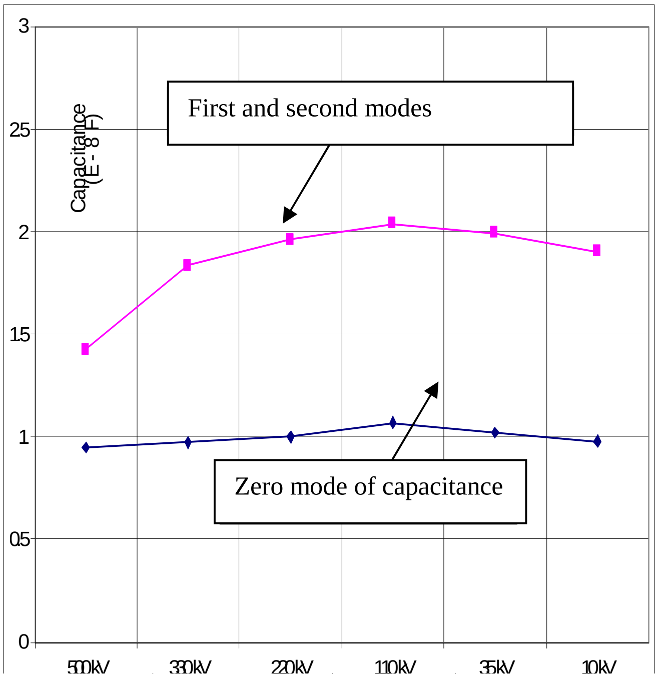


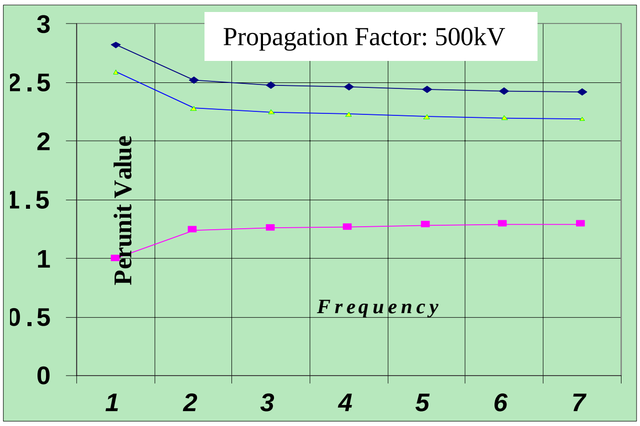
Fig 2 The computed values for the capatitance in the wave modes of different lines

It should be mentioned that, the wave modes are individual channels without any mutual relationship between them and they are defined as **{(α), (β), (0)}** as deduced in appendix [10]. It is marked that the speediest wave mode is the first **(α)** while the second **(β)** is slower a little. The last important wave mode is the zero wave mode (**0**) which is depending on the earth return effect. This earth is normally a non homogeneous medium either vertically or horizontally. This item has a great interest of the research field because all unexplained phenomena may relate to it. It is seen that, both first and second wave modes in modal coordinates are practically the same and varying in the same manner although the zero mode value can be considered a constant for all levels of voltage.

Therefore, the parameters of the system must be evaluated. So, a capacitance is calculated for different phase geometry shapes in modal coordinates as seen in Fig. 2. Its value is increased in the second wave mode for the Extra High voltage **(EHV)** and ultra High voltage **(UHV)** while it still a constant for the High voltage **(HV)** level till the distribution system. In the distribution system the effect of the capacitive reactance on the presence of transients is decayed after the 100 kV level and before the 35 kV level. It begins the decrease process before the 35 kV level.

It is important to indicate that the transient analysis, generally, contains both time and frequency domain where they sometimes are mixed together or otherwise, the transformation

from one to another may be required. In some methods the procedure of solution tends to model a three-phase transmission line directly in time domain, without the explicit use of inverse transforms for simplicity. This must take into account the frequency-dependent parameters of the line, considering both the soil and the skin effects. Furthermore the accuracy of the developed results should be verified, in frequency domain, by a simple methodology based on line distributed parameters and transfer function related to the input / output signals of the lumped parameters representation. The commercial software of electromagnetic transients program (**EMTP**) may be considered for check of results of new methods.



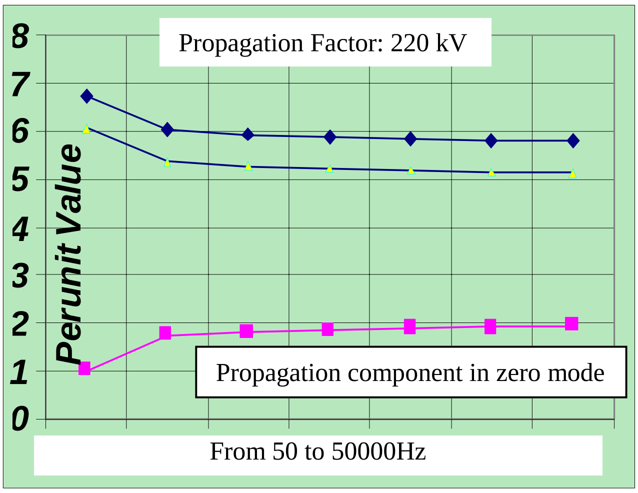


Fig 3 Variation of propagation coefficient for the studied lines(for voltage level of 500&220kv)

Two limits (upper and lower) are indicated where both channels {1st **(α)** & 2nd **(β)}** have a higher value than that for the zero wave mode (**0**). It is increasing with voltage level in the two modes but it is a constant in the zero wave mode **(0**). The propagation coefficient is varied in these coordinates a shown in Fig. 3 where per unit system is considered for the value. Also, the variation has been computed according to the frequency in the frequency domain.

The frequency presence inside the processes of transients may reach 60 kHz due to the high frequency **HF** loads and interference with electromagnetic fields. The 50 Hz t zero mode position is taken ass the reference (unity value) and then its value is illustrated for studied voltage levels. The coefficient is increasing with frequency in Zero mode coordinates while it is decreased in other channels. The maximum ratio of this coefficient is appeared for 110 kV, where the 35 kV distribution lines approaches the case of 500 kV. This approves that the distribution network is subjected normally to heavy transients relative to its level where its value may exceed that for **EHV** levels. This coefficient can be shown mathematically in each channel from equation (6) to obey the formula 7 in the appendix.

On the other hand, the propagation factor, as shown in Fig. 3. illustrates that there is a difference between both first and second wave modes where the first wave mode has a maximum value for all levels of applied voltage. This indicates that the first wave mode is the speediest one while the zero wave mode has the slowest. Contrary, the zero mode parameter begins at lower value which increased with the rise of frequency. The frequency means the presence of harmonics in the real wave forms. These forms can not be sinusoidal as the normal operation conditions but the increase of higher frequency means more harmonics. The propagation factor becomes constant quickly and becomes frequency independent in all three modes.

However, the attenuation factor plays great role in the limitation of the over-voltages since it is representing the effective part of the propagation process. The characteristic of the average transient voltage calculated with respect to the nominal operating voltage is shown in Fig. 4 where the maximum ratio is corresponding to the higher voltage class. The **PER UNIT** system is considered where the nominal operating voltage has been the reference value for each one.

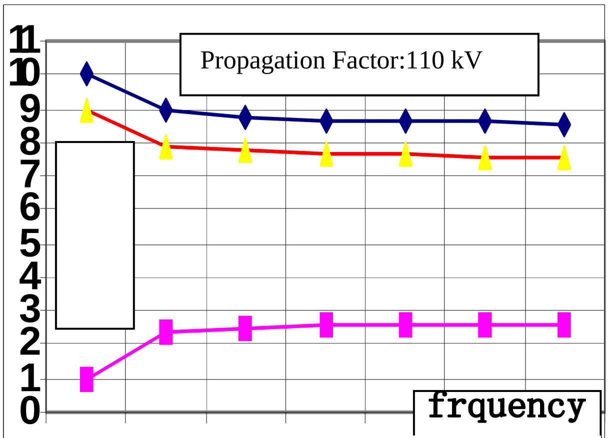


Fig 3 (b) Variation of propagation coefficient for the studied lines(for voltages level of 110kv)

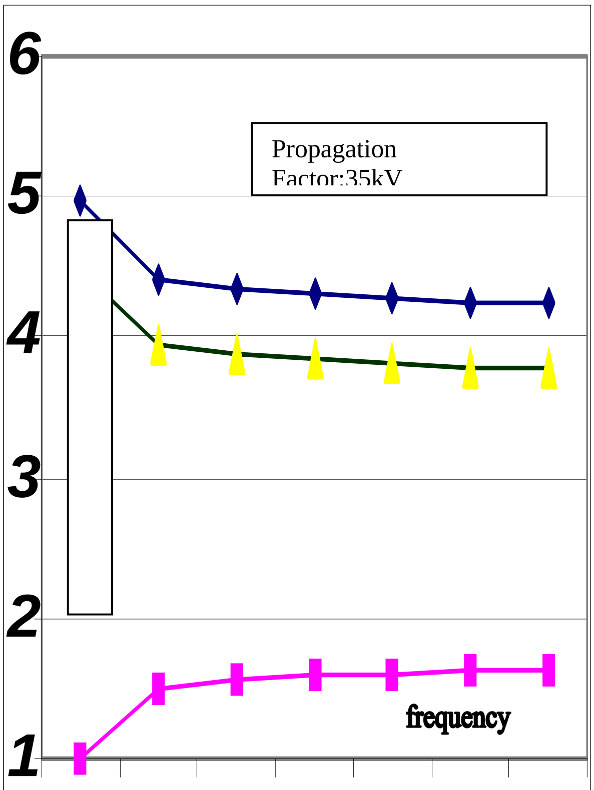


Fig 3 (c) Variation of propagation coefficient for the studied lines (for voltages level of 35kv)

It should be indicated that, the attenuation factor is very high for **UHV** and **EHV** but is highly decreased in the distribution systems after the 35 kV level networks. Also, the **HV** level gives a constant effect for the value of attenuation factor where this region begins at 220 kV up to the distribution level of 35 kV.

However, the wood tower standards give a lower attenuation so that its value for 35 kV towers may exceed that for the 110 and 220 such towers. The derived equations will be more complicated for the non-transposed lines in the **LAPLACIAN** domain (**p**) and so the initial formula can be solved in modal coordinates. Also, the distribution networks play an important role in the operation conditions s analyzed before [8]. Many methods are known for the transient calculations and the wave mode propagation method will be selected because it is valid for either transposed or non-transposed lines. It mainly depends on the transformation matrix [**T**], which takes the form of equation 8 in the appendix.

If the basic differential equations (2) are specified to the modal coordinates, new deduced expressions become individually (equation 9 of the appendix). Then, voltage and current at point **x** in modal coordinates will be in the form of 10 in the appendix. These equations depend on the transformation of the phase system into another one, which is known as the wave mode system. This means that the wave modal concept has three isolated modes without any mutual effect between them as this can be reached through the mathematical theorem of Eigen values and **Eigen** vectors. It should be noted that the transformation matrix of equation 8 is the **Eigen** vectors for the system.

A special program is used for the calculations of parameters in wave modes or the transients and modified to measure the statistical values as presented here. The application of parameters in modal axes is based on the matrix equation 11 (See Appendix).

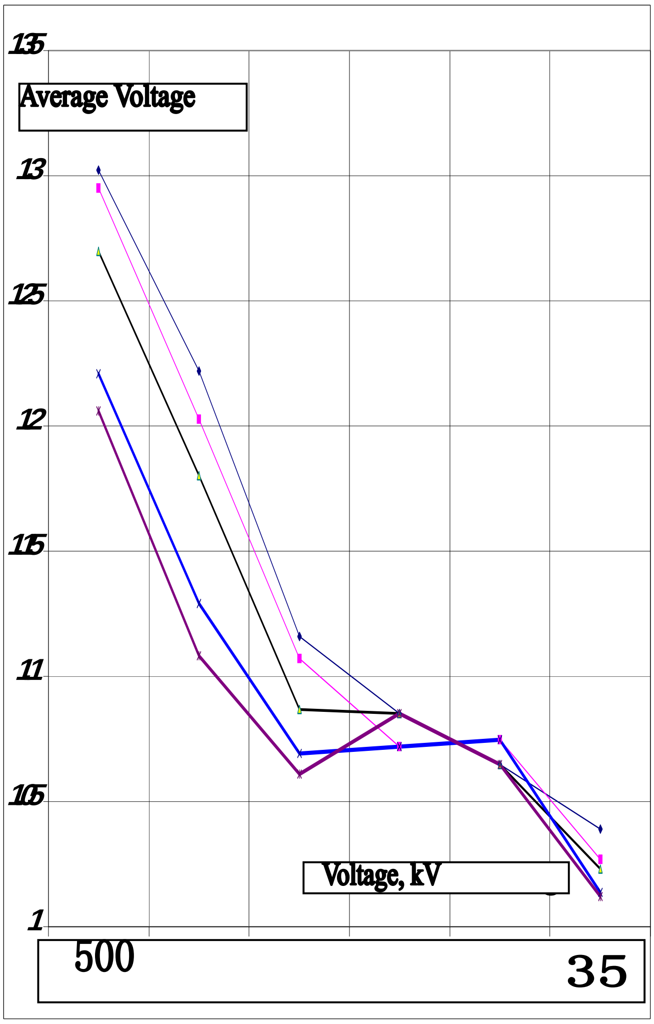


Fig 4 (a) The mode performance for average transient voltage at different nominal operating voltages

For easy computation these equations must be referred to the voltage source at the sending end instead of the voltage t receiving end. Then, a simplified formula for voltage and current (equation 12 of Appendix) can be derived (See Appendix). It would be indicated that the voltage source differs from that at the sending end of line according to the relation (equation 13 in the appendix). Consequently, the voltage may be formulated through the transformation matrix (See formula 14 in the appendix). Therefore, voltages in phase coordinates can be determined numerically according to the convolution

theorem [12] as given in appendix (equation 15). Similarly, the equations of currents in phase coordinates can be found [12].

It is seen from Fig. 4 that, the maximum value for the standard deviation is appeared at the distribution systems where it comes at the voltage level of 35 kV. This indicates that the distribution level may be also, affected by the switching processes. This leads to the importance of the use of the capacitive banks in the distribution level. So, the automated units for compensation in the distribution systems would be checked for all conditions because the deduced results give a danger pointer for the presence of transients in such systems.

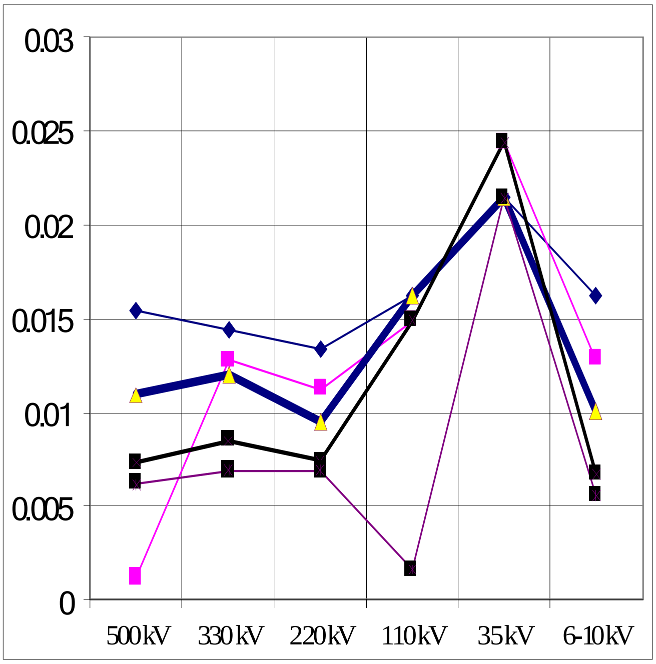


Fig 4 (b) The calculated standard deviation at different nominal operating voltages

3 . STATISTICAL SWITCHING TRANSIENTS

Moreover, the variation of time domain length has been examined as given in Fig. 5. Interval duration of 0.21 ms was considered for 100, 200 and 400 points of calculation. The attenuation effect is drawn in Fig. 5 in frequency domain while Fig. 5, (a) illustrates the variation in the first mode. Fig. 5, (b) shows this dependency for the most important wave mode which is the zero wave mode. Its importance comes from the slow of traveling waves according to the natural values of the elements and components in the transmission lines with distributed parameters. It should be mentioned that, the consideration of asymmetry not only for the distributed parameters but also the absent of transposition between phases.

It is seen from Fig. 5 that, the distribution system at the level of 35 kV has a great values that exceed the transmission system.

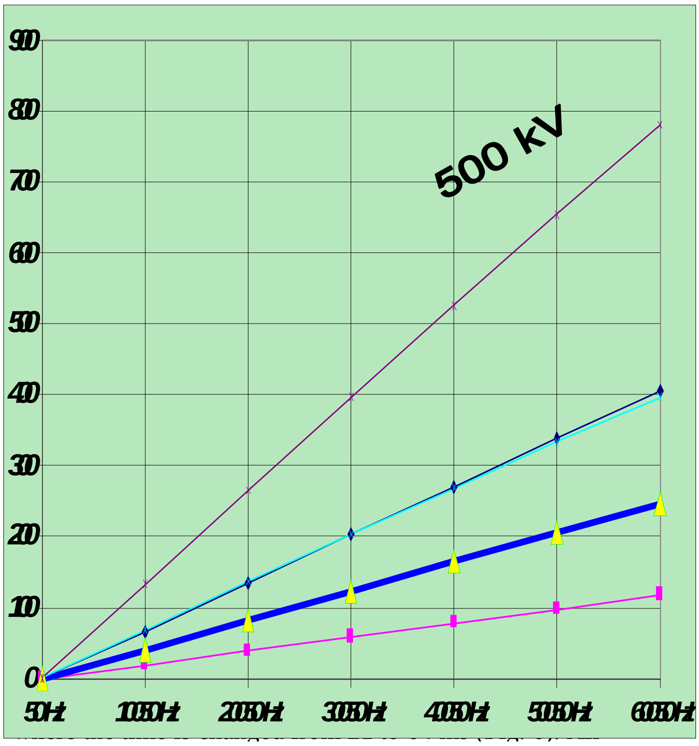


Fig 5 (a) average over-voltage at the receiving end of lines for different values of intervals

calculations are based on the voltage at the receiving end of transmission lines. The results prove that the small interval for the calculations gives a rise in the average transient voltage and consequentially, the evaluated number of transient voltage.

In the above results, the combination of changing of either interval or number of points in the domain length clarified the effect of steady state presence in long time term for 500 kV. The low voltage distribution system (6-10 kV) gives gradually decrease with time domain length while it is approximately constant for 35 kV. Thus the choice of the small interval of calculations must be considered, and accordingly a suitable duration for the overall time of calculations should be taken. This means that the steady state time after switching processes would be eliminated as possible in order to get real exact results.

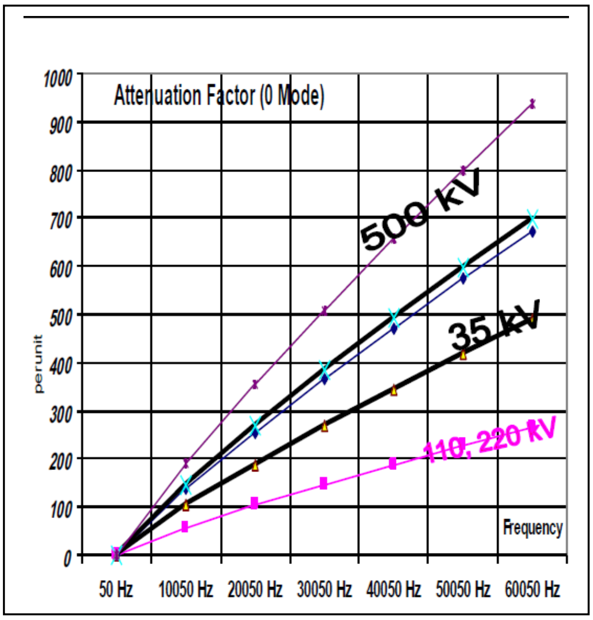


Fig 5 (b) attenuation factor for waves at the receiving end of lines for different values of intervals (zero mode)

Also, the overall average voltage for studied lines is decreased due to the presence of steady state period inside the process of calculations. Otherwise, the effect of interval only for a constant value for the points of computations (300) is considered and the results are listed in Table 3 for both verge voltage and standard deviation.

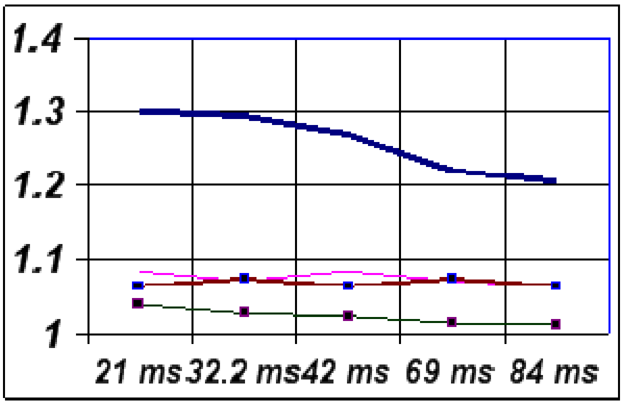


Fig 6 (a) Number of over-voltages at the receiving end of lines for different values of intervals (%)

Therefore as it is concluded that, the choice of time interval for the computational analysis affect on the results of proposed number of transients so that an optimal value for the chosen interval would be pre-selected before the study of any condition. Also, this number will be a good measurement for the presence of over-voltages inside a process where the sever cases must be avoided. The planning for the transmission systems as well as the distribution systems should account the phenomena of transients so that its consideration may be a vital parameter for the design body. The transmission systems take the major importance in this presented occasion because the transient level will be very high so that its effect may be accounted as a first step in the planning scheme. This effect may be disappeared in the distribution level at the consumer use.

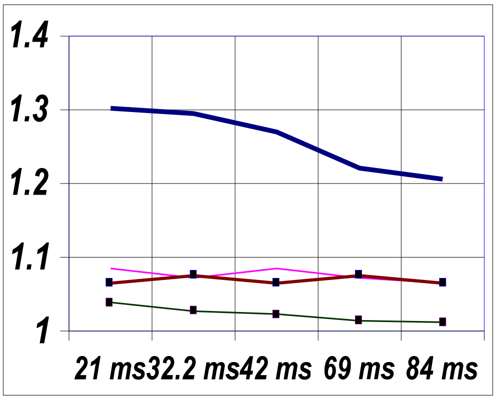


Fig 6 (b) Number of over-voltages at the receiving end of lines for different values of intervals (%)

4 . TRANSIENT NUMBER

The transient presence in a system during the switching processes may be necessary to measure the level of its action on the insulation level. This paper presents a new proposed number for such simulations in order to measure the transient content **TN** in a system. It represents the percentage presence of over-voltages inside the time length considered and so, it can be expressed mathematically in the form:

$$\mathbf{TN = N_t / K} \qquad (1)$$

The presence of transients for each case is drawn in Fig. 7, a, but the overall presence will be shown in Fig. 7, b. It is seen that, the transient level is always decreasing with voltage level except some readings of 220 kV relative to 110 kV due to the closed dimensions of towers for both levels (Table 1). This voltage is decreased with respect to the interval, which reflects the total time domain length. This confirms the deduced results above of Fig. 6. Also, the same conclusion can be derived from Fig. 7, b.

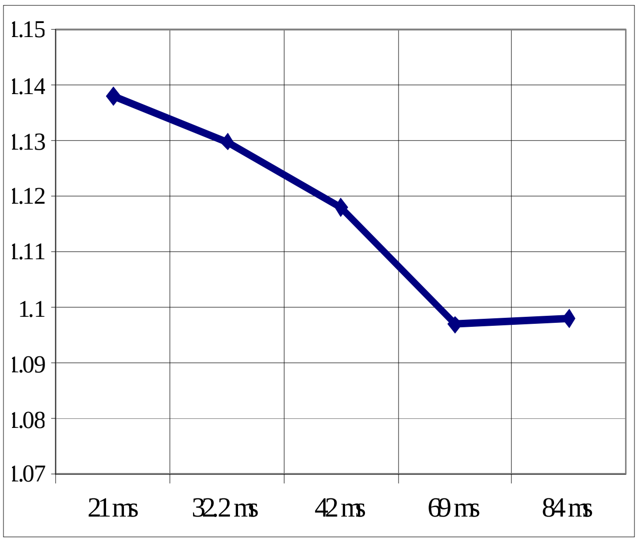


Fig 6 (c) Number of over-voltages at the receiving end of lines for different values of intervals (%)

Table 3, a: Average voltage level and standard deviation σ at receiving end **R E** of lines for different duration of intervals at K=300 (ms)

kV	23 *(ms)*		22 *(ms)*	
	V_o	σ	V_o	σ
500	**1.221**	**.007315**	**1.23**	**.007373**
330	**1.129**	**.00846**	**1.135**	**.00902**
220	**1.069**	**.00739**	**1.075**	**.007491**
110	**1.072**	**.01488**	**1.085**	**.0147**
35	**1.075**	**.02439**	**1.065**	**.02348**
6-10	**1.014**	**.006732**	**1.015**	**.007079**

Table 3, b: Average voltage and standard deviation σ at the receiving end of lines for duration of intervals at K=300 (ms)

kV	21 *(ms)*		12 *(ms)*	
	V_o	σ	V_o	σ
500	**1.23**	**.007972**	**1.291**	**.008629**
330	**1.135**	**.008887**	**1.218**	**.009699**
220	**1.075**	**.008276**	**1.123**	**.00754**
110	**1.085**	**.0162**	**1.081**	**.009005**
35	**1.065**	**.02144**		
6-10	**1.015**	**.006912**		

This table lists the average voltage as well as the standard deviation for each studied voltage level with respect to the duration of calculations. So, both standard deviation value and the average transient voltage are decreased with the increase of the duration of calculations in spite of the small difference between all durations.

Fig. 7 ensures the above conclusion corresponding to the long time choice where the steady state condition may be reached. This is appeared at the time of 63 ms the transient contents become less than 1.1 although it is very large value for 36 – 60 ms instead. This value will be decreased a little in the range of 60 – 63 period of the calculation. Thus, a small time not exceeding the calculation period of 60 ms may be proposed for applications.

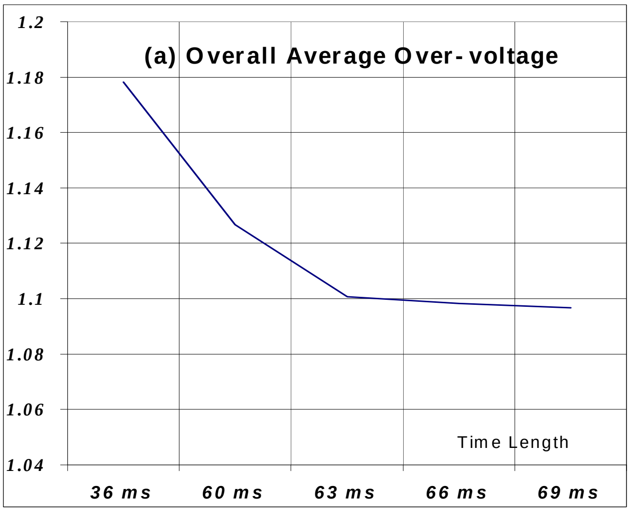


Fig 7 (a) The result for the studied lines at different duration intervals at(K=300)

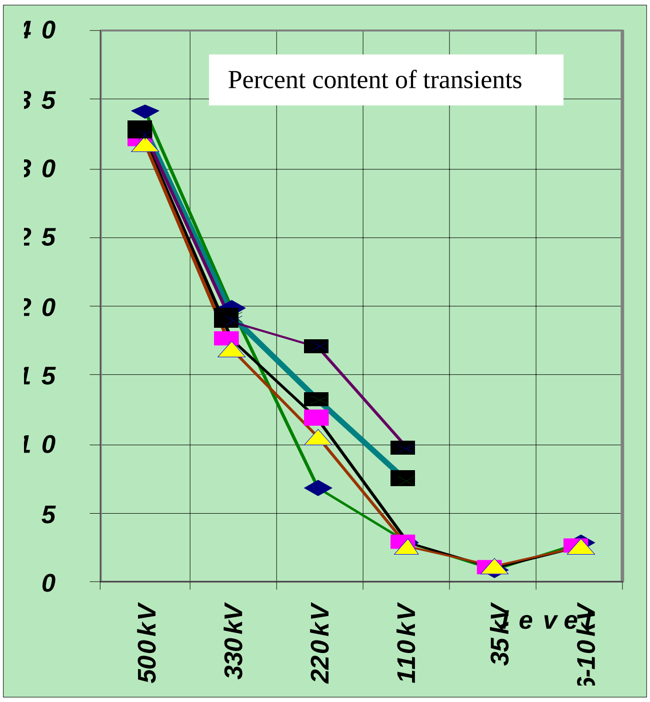


Fig 7 (b) The result for the considered lines at different duration intervals at (K=300)

In other words, Fig. 7 presents a large value of percentage content of transients in the system is appeared at the 500 kV for all dimensions of this class of voltage where it varies between 1.35 and 1.2. This value is steeply decreased for the distribution system where the transient switching voltages are computed as 1.01 up to 1.03. In a midpoint lies the transmission of 330 – 110 kV level where its content varies between 1.2 and 1.07.

5 . COMPENSATION EFFECT

The reactive part of elements connected to a power system takes a part in the switching processes as soon as voltage control in the distribution system needs shunt capacitor on

loads. This may be transferred (directly or non-directly) to the low voltage line in the case of heavy loads. This capacitor may be appeared also in **EHV** and **UHV** transmission systems.

The design of transmission systems depends to a great extent on the computational analysis of switching transients because the generated voltages in switching processes will be danger so that the insulation level must be stated to be able to withstand with these high voltages. Contrary, in the distribution systems the switching processes may be at a less level of importance although this is not the general rule as it is appeared in the above results. This may be seen from the value of the calculated value of over-voltage in the system where it is generally permits the use of capacitor banks for the power factor corrections.

Whatever, the load type has been tested where both inductive and capacitive loads are introduced at the receiving end of the switched lines. Results are shown in Fig. 8 for the inductive condition for a time length of 200 points with .023 ms interval. It shows a normal characteristic while the heavy transients appear with the second condition (capacitance).

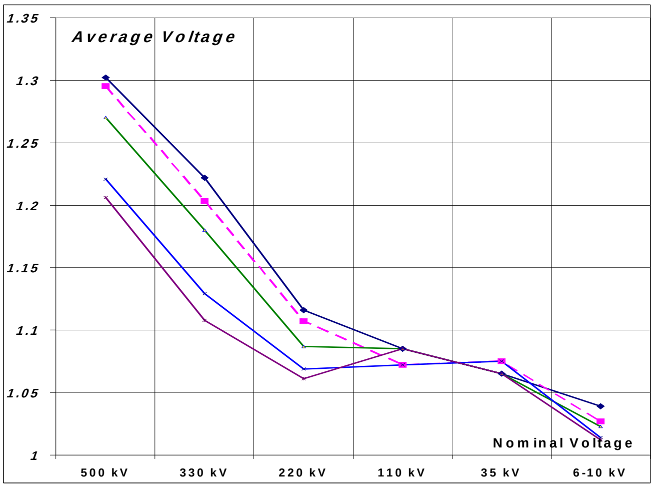


Fig 8 (a) The average value of voltage for the inductive load effect on transient processes

It is very important to avoid the presence of the capacitive reactance in the elements of the power system because it has a danger effect on the recovery voltage. This may be expressed here through the presence of transient voltages issn the system where it may be reflected by the transient number. Consequentially, the harmonics may be too generated due to the presence of capacitance in the system. So, the nonlinearity characteristics could become more complicated in the solution in closed form.

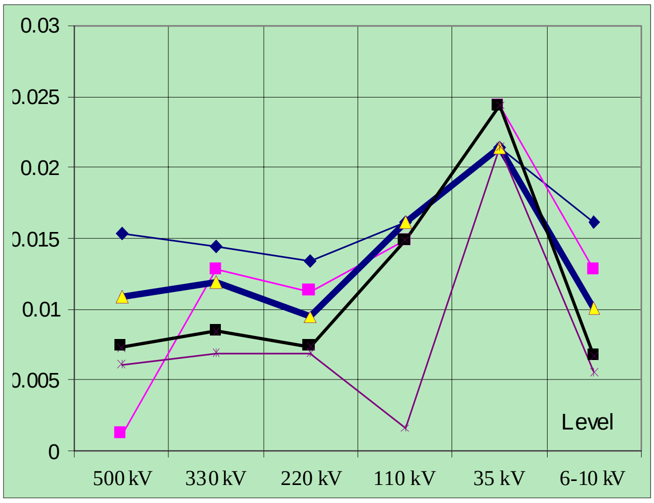


Fig 8 (b) Standard deviation for inductive loads

It would be required to indicate that the capacitive effect reached faster in the distribution system. It began at 10 Ohms for 6 kV with a per unit value of 37.14 wshile this value became 16.82 for 35 kV lines. The other lines still in the normal but the resonance condition may come later. It varied with potential level as the final will be the highest one.

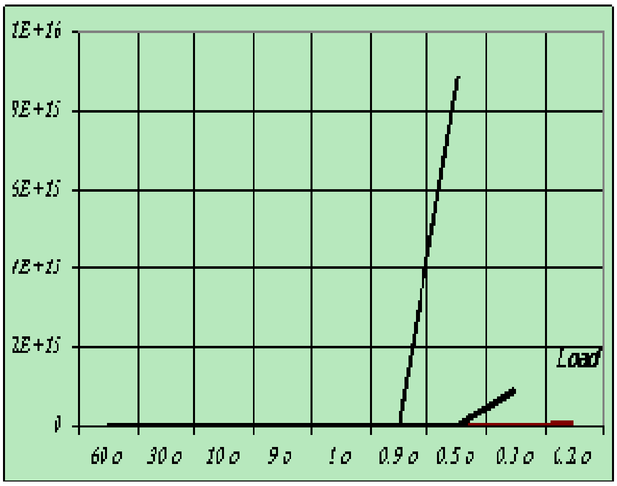


Fig 9 (a) Average Transient voltage for capacitive loads

The effect of capacitive load on the transient profile could be a danger because it contains a lot of harmonic of high orders. This means that resonance characteristics may be appeared due to switching processes

The resonance characteristics are shown through curves in Fig. 9 although the standard deviation became very large. This means that the value of actual maximum voltage is high. The curves for 220 and 330 kV are not illustrated.

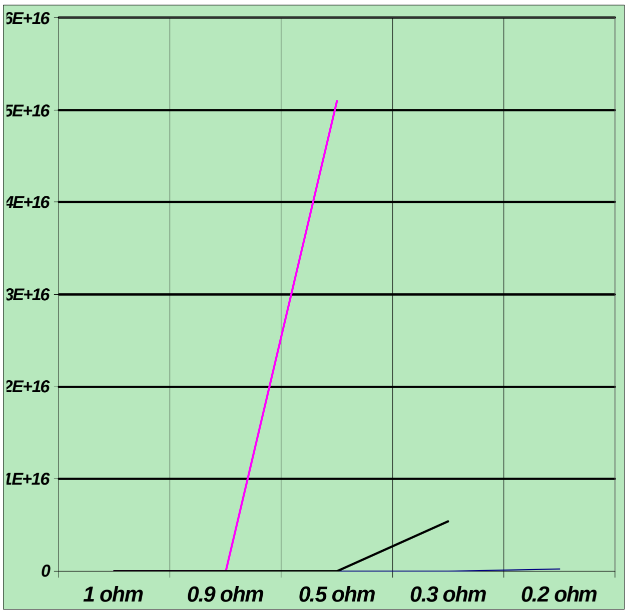


Fig 9 (b) Standard deviation for capacitive loads

Fig. 10 shows well that the presence of transient inside the time length is higher with nominal potential and it is very high for the capacitive condition. The average voltage distribution at the receiving end of the lines studied but for all possible lengths is computed as given in Fig. 11.

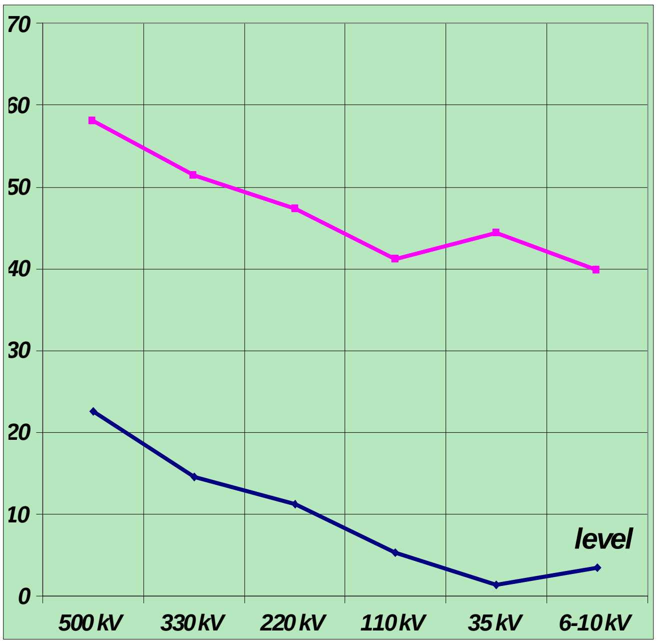


Fig 10 The overall transient number in both cases of inductance and capacitance

It proves that the switching transients in EHV and HV lines will have a great role in the design of such lines and it decayed for the distribution system. Also, the effect of line length shows an average value for each length in spite of the different potentials (Fig. 11, b).

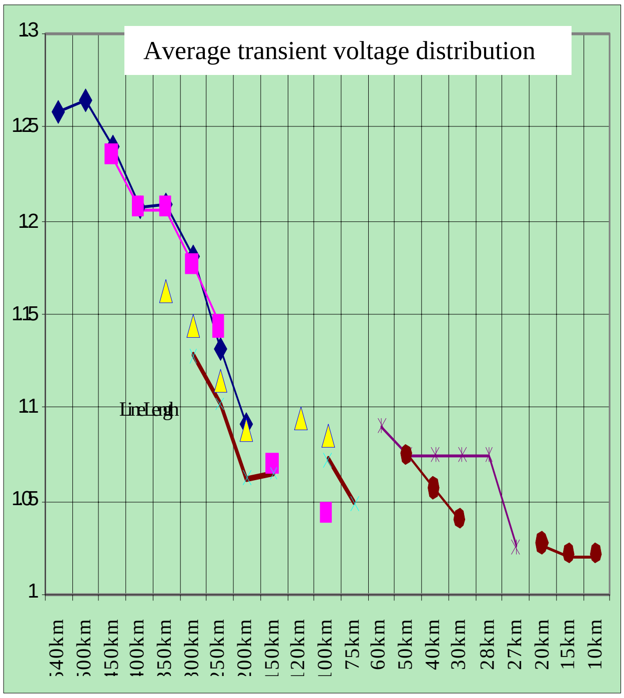


Fig 11 (a) The calculated average value for different line lengths at K=200

The derived standard deviation is drawn in Fig. 12 with different lengths of lines when the transient number is presented in Fig. 13. These curves indicated the same conclusion defined above.

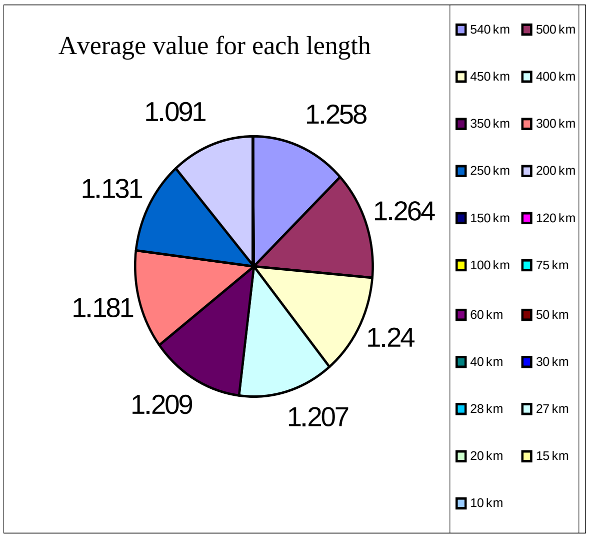


Fig 11 (b) The calculated average value for different line lengths at K=200

Nevertheless, the shunt compensation by the installation of rector at receiving end would be the best solution for long lines **EHV** and **UHV** systems due to the reduced statistical transient presence (as the value of **TN**). Whatever, shunt capacitors on feeders of thee distribution networks represent critical condition with bulk reactive powers so

that a great interest would be needed with sudden change of load according to the performance of load curves at such points.

6. STATISTICAL PROFILE

The process of profiling for a group of data may be expressed mathematically either through a deterministic or by a stochastic concept. The deterministic style is a mathematical model, which means the actual specified all data are included in the system while the stochastic concept gives an overall view for the system through either all data or some random values.

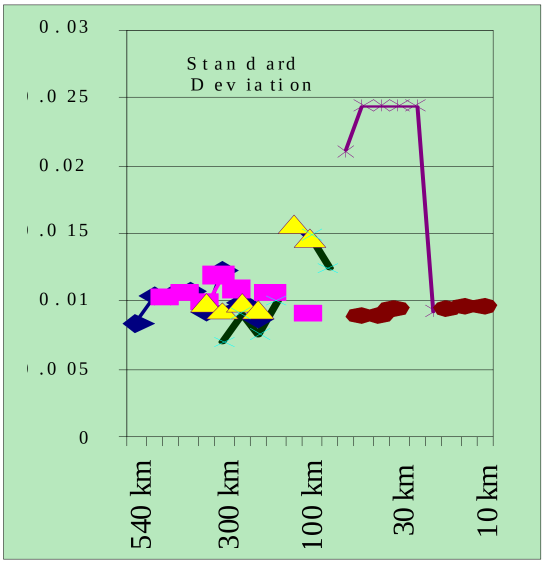


Fig 12 The calculated average value for different line lengths at K=200

Although this last concept may introduce an error according to the statistical principles, a good result expressing a problem can be easy achieved [13, 14]. This will be more difficult with the internal transients. Therefore, the above analysis can be used to get a general profile for the processes of switching transients in a certain specified network.

Any network contains different numbers of distribution and transmission systems with various connections [15, 16]. There is a specified ratio of these systems to a certain moment but this ratio will be varied with each extension, which must be normally happened, continuously, at least in the distribution system. Nowadays, new concepts of modern techniques would be needed so that the Artificial Neural Network (**ANN**) can be implemented for the modification of the operation in electric power networks [17 - 19]. So, the ratio between both systems inside the network will be actually a dynamic ratio. Therefore, a general profile for such specified network at a certain moment can solve the problem of generalization of the view for this network. Thus, the distribution to transmission ratio (DTR) my be defined by

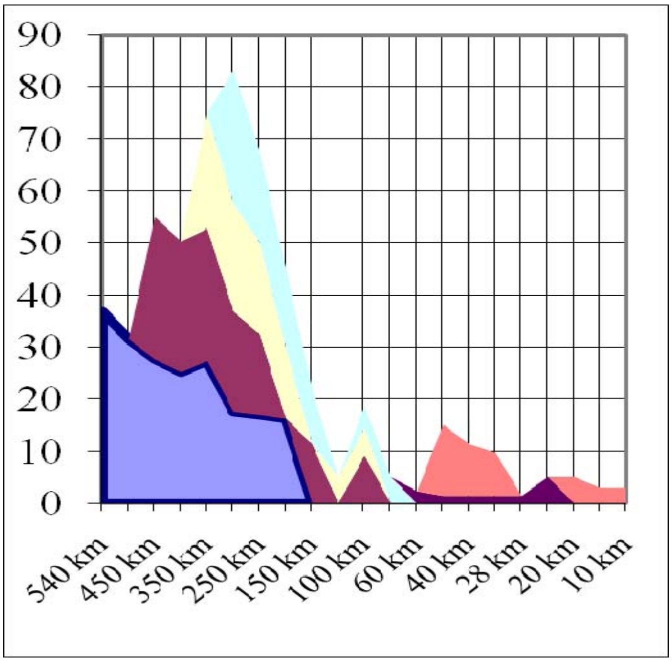


Fig 13 The deviation transient for different line lengths at K=200

$$\textbf{(DTR)} = \Sigma\,(Z_l)_D / \Sigma(Z_l)_T \qquad (2)$$

Consequentially, line impedance can be computed according to the specific resistance and inductance multiplied by the length and then, the summation of impedance for either transmission or distribution would be evaluated. After that, a defined profile for a network should be deduced for at a certain network at a specified time but a general profile for this network may be evaluated at all values of (**DTR**).

On the other hand, a general ratio (**GR**) may be proposed as:

$$\textbf{(GR)} = \textbf{DTR} / (1+ \textbf{DTR}) \qquad (3)$$

Table 2: The Statistical proposed value for the percentage content of transients in:

systems		*(a) transmission*			
	kV	500	220	110	*$(N_t)_T$*
Z	(p. u.)	13.2	4.8		2.8
Case	Base	30	20	21.3	30
	1st	30	20	21.3	10
	2nd	30	20	21.3	10
	3rd	30	20	21.3	10
	4th	30	30	20.7	10
	5th	40	20	23	10
systems		*(b) distribution*			
	kV	35	11	6	*$(N_t)_T$*
Z	(p. u.)	1	1.36		4.8
Case	Base	50	20	10.15	20
	1st	60	30	12.4	20
	2nd	50	40	15.55	20
	3rd	40	60	22.1	20
	4th	40	60	22.1	30
	5th	40	60	22.1	20

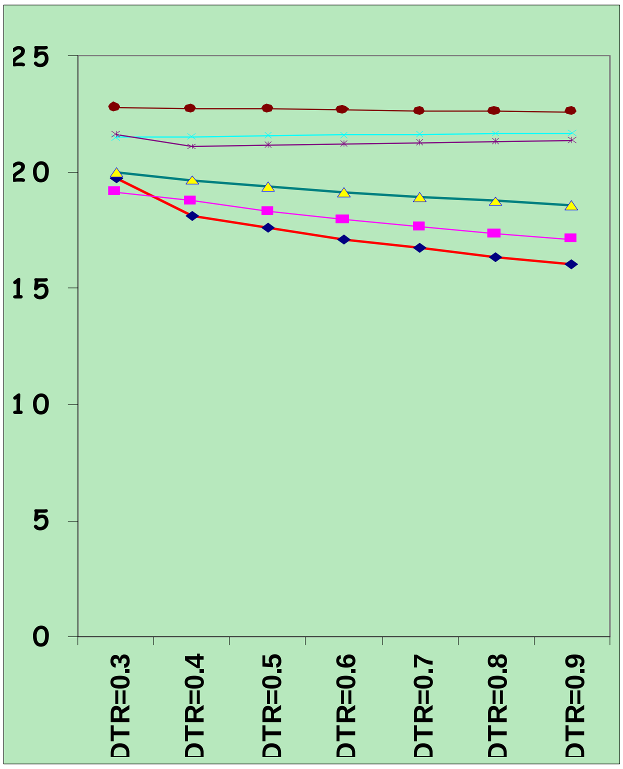


Fig 14 The deduced profile for the proposed cases of transmission and distribution system

This will be useful to find the general profile for a network through the general transient number by:

$$TN_G = (GR)[\ (N_t)_D - (N_t)_T\ ]/K\ +\ (N_t)_T / K \qquad (4)$$

This general transient number may be evaluated for system specified, but it may be important to find its change due to the growing in the electric systems as a whole. So, a basic configuration for a power system is suggested as listed in Table 2 where both transmission and distribution systems re indicated according to the self parameter for each voltage level.

Then, different cases with the variation of such power system are considered on the bases of normal growth in the developing counties. The impedance is referred to the 11 kV impedance as calculated statistically above while the percentage content for either the transmission (500, 220, 110 kV) or the distribution (35, 11, 6 kV) level with the determined transient number. Therefore, the constant configuration for the transmission system is considered (basic case), where the variation is applied to the distribution level. The general transient number is computed for each case as shown in Fig 14.

Also, the change in the transmission system is given (cases 4 and 5). It is shown that the transient content in a network will be increased with the growing in the distribution network. This may give more increase with the great extension in the lower level of voltage so that a corresponding extension will be needed as proved for the case 4, where the 110 kV increased. It should be indicated that this extension balance cannot be achieved t the highest UHV scale (case 5).

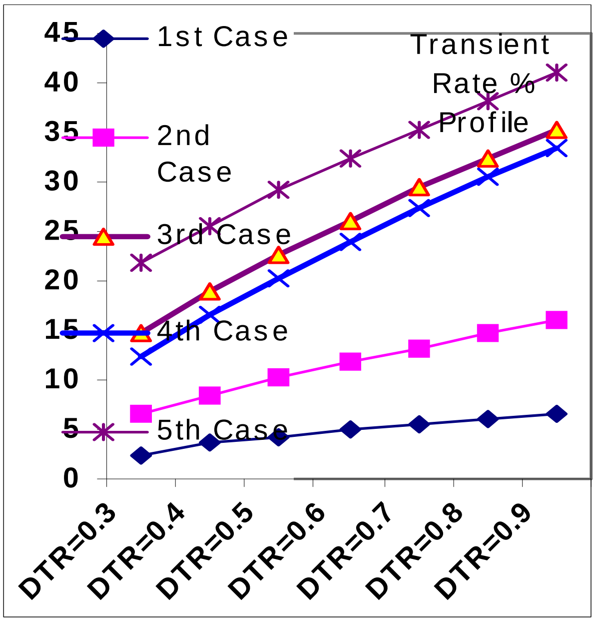


Fig 15 The determined rate of rise of the transient content referring to the base case for the proposed cased of transmission and distribution system (%)

Thus, the proposed technique will be useful for the planning and design of power systems in order to decrease the transient level inside a network [20]. This may be clarified with the rate of rise of the transient content as given in Fig. 15 for the studied cases referring to the basic one. The rate of rise is increased with 6 kV (35 %) although it reaches 40 % for the **UHV** extension. This proves that the proposed concept for the general transient number must be considered for any extension to avoid the heavy presence of transients in a power system.

7 . CONCLUSION

This work reported a statistical evaluation of the switching processes in transmission and distribution systems with earth return effect. The frequency dependence of the parameters was investigated and the random values for the closing angle of circuit breakers were statistically taken as well.

The paper has proposed a simplified concept for the evaluation of transients in both transmission and distribution systems through the transformation into the so called the wave mode coordinates. Also, it is valid for both transposed and non-transposed phases.

The use of bulk capacitors in the distribution power network has been tested for the transient presence in a percentage style with the limits of resonance phenomena.

The overall transient number for the power network in a statistical base has been realized so that the **UHV** and **EHV** still have the heavier transient presence.

The statistical profile is a good tool for the planning and design of power systems especially with the quick developing

networks. This case may be appeared in the developing countries where the great density of population will be presented.

APPENDIX

The presented method here depends on the transformation of the problem in the time domain (with mutual effect between phases) into a new frequency domain (3 independent modes). Then, the solution will be easy to done where the final solution in frequency domain must be returned to the time domain expression using the inverse transform technique. This process will be based on the deduced general transformation matrix [**T**]. It is valid for all types of lines either transposed or un-transposed transmission lines.

Moreover, the asymmetry of the problem either in transposition or the return path can be considered. This return path is the earth return effect where it is simulated mathematically and introduced in the values of the parameters such as: resistance **R**, capacitance **C**, potential coefficient, inductance **L** , surge impedance $\mathbf{Z_c}$, attenuation factor α, and propagation coefficient γ**.** These all parameters are investigated in the present paper above. A differential equation in time domain becomes three linear simple equations in the wave mode coordinates (α, β, 0) where their inverse will be simple as given in this Appendix.

The impedance **Z** of an electric system in its real **R** and imaginary **X** parts may be expressed in the matrix form by

[Z] = [R] + j [X] =

$$\begin{pmatrix} R_c+R_g \\ R_g \\ R_c \end{pmatrix} \begin{pmatrix} R_g \\ R_c+R_g \\ R_g \end{pmatrix} \begin{pmatrix} R_g \\ R_g \\ R_c+R_g \end{pmatrix} + j\,\omega \begin{pmatrix} L & M & M \\ M & L & M \\ L & M & M \end{pmatrix} \quad (1\ a)$$

The return effect is introduced through the ground earth resistance where the Carson analysis would be considered. It assumes that the ground resistance is a frequency dependent parameter.

Thus, the general differential equation of a transmission line could be stated as

$$\begin{aligned} &-d/dx\,[V(x)] = [Z]\,[I(x)] \\ &-d/dx\,[I(x)] = [Y]\,[V(x)] \end{aligned} \quad (2\ a)$$

The solution of these equations can be deduced for the voltage **V(x)** at a point **x** on the transmission line in the form:

$$V(x) = (1/3)\{ch\,\gamma_1(l-x)\,[M_1] + ch\,\gamma_2(l-x)[M_2])\,[v(l)]\} + (1/3)\{Z_1\,sh\,\gamma_2\,(l-x)\,[M_2] + Z_2\,sh\,\gamma_1\,(l-x)\,[M_1])\,[I(l)]\} \quad (3\ a)$$

Where the matrices of constants M_1 and M_2 are formulated as

$$[M_1] = \begin{pmatrix} 1 & 1 & 1 \\ 1 & 1 & 1 \\ 1 & 1 & 1 \end{pmatrix}, \quad [M_2] = \begin{pmatrix} 2 & -1 & -1 \\ -1 & 2 & -1 \\ -1 & -1 & 2 \end{pmatrix}$$

Also, the impedances $\mathbf{Z_1}$ and $\mathbf{Z_2}$ can be expressed by

$$Z_1^2 = \{R + p\,(L - M)\} / \{p\,(C - C_m)\}$$

$$Z_2^2 = \{R + 3R + p\,(L + 2M)\} / \{p\,(C + 2\,C_m)\}$$

Similarly, the current **I(x)** at a point x would be deduced by the expression

$$[I(x)] = \{sh\,\gamma_2\,(l - x)\,[Z_c]^{-1}\,[v(l)] + ch\,\gamma_1\,(l - x)\,\,[I(l)] \quad (4\ a)$$

The propagation coefficient γ can be formulated in the matrix form

$$[\gamma] = (1/3)\{\lambda_1\,[M_1] + \lambda_2\,[M_2]\,\} \quad (5)$$

It should be mentioned that the value of λ variables would be given in the relationships:

$$\lambda_1^2 = \gamma_1 + 2\,\gamma_2 \ \&\ \lambda_2^2 = \lambda_3^2$$

The expansion of these relationships can be estimated in the form:

$$e^{[\gamma]\,x} = (1/3)\{\,e^{\lambda_1 x}\,[M_1] + e^{\lambda_2 x}\,[M_2]\,\} \quad (6)$$

$$e^{[\gamma]\,x} = e^{\gamma_\alpha x}\{(\gamma_\beta - \gamma)\,(\gamma_0 - \gamma)\}/\{(\gamma_\beta - \gamma_\alpha)\,(\gamma_0 - \gamma_\alpha)\} + e^{\gamma_\beta x}\,\{(\gamma_\alpha - \gamma)\,(\gamma_0 - \gamma)\}\,/\,\{(\gamma_\alpha - \gamma_\beta)(\gamma_0 - \gamma_\beta)\} + e^{\gamma_0 x}\,\{(\gamma_\alpha - \gamma)(\gamma_\beta - \gamma)\}/\{(\gamma_\alpha - \gamma_0) \times (\gamma_\beta - \gamma_0)\} =$$

$$= e^{\gamma_\alpha x}\begin{pmatrix} 1 & 0 & 0 \\ 0 & 0 & 0 \\ 0 & 0 & 0 \end{pmatrix} + e^{\gamma_\beta x}\begin{pmatrix} 0 & 0 & 0 \\ 0 & 1 & 0 \\ 0 & 0 & 0 \end{pmatrix} + e^{\gamma_0 x}\begin{pmatrix} 0 & 0 & 0 \\ 0 & 0 & 0 \\ 0 & 0 & 1 \end{pmatrix} \quad (7)$$

For the non-transposed lines the transformation matrix is expressed in the general form as

$$[T] = \begin{pmatrix} 1 & 1 & 1 \\ 0 & -B & A \\ -1 & 1 & 1 \end{pmatrix} \quad (8)$$

This matrix **[T]** is the transformation matrix from the time domain analysis into the frequency domain expressions although its inverse $\mathbf{[T]^{-1}}$ may be needed for the inverse transform in the opposite direction of transformation. It is the transformation matrix for the modal analysis. Its special case for the symmetrical lines gives the well known matrix "Clarke Matrix" where **A = 1 and B = 2.**

Thus, the equations should be solved in the wave modal coordinates (α , β , 0) as given below:

$$\begin{aligned} &-d/dx\,[V(x)_{\alpha,\beta,0}] = [Z]\,[I(x)_{\alpha,\beta,0}] \\ &-d/dx\,[I(x)_{\alpha,\beta,0}] = [Y]\,[V(x)_{\alpha,\beta,0}] \end{aligned} \quad (9)$$

These equations may be simplified as

$$[V(x,p)]_{\alpha,\beta,0} = [ch\,\gamma\,(l-x)]_{\alpha,\beta,0}\,[V(l,p)]_{\alpha,\beta,0} + [sh\,\gamma\,(l-x)]_{\alpha,\beta,0}\,[Z_c]_{\alpha,\beta,0}\,[I(l,p)]_{\alpha,\beta,0}$$

$$[I(x,p)]_{\alpha,\beta,0} = [sh\,\gamma\,(l-x)]_{\alpha,\beta,0}\,[Z_c]^{-1}_{\alpha,\beta,0}\,[V(l,p)]_{\alpha,\beta,0} + [ch\,\gamma\,(l-x)]_{\alpha,\beta,0}\,[I(l,p)]_{\alpha,\beta,0} \quad (10)$$

In the above expressions the characteristic impedance $\mathbf{Z_c}$ is appeared in the wave mode coordinates. The inverse of the transformation matrix may be appeared with the impedances in the form

$$\mathbf{[E] = [T]\ [Z_c\ ch\ \gamma\ l / sh\ \gamma\ l]\ [T]^{-1}[I\ (0)]} \quad (11)$$

So, we can get the voltage **V(x,p)** and current **I(x,p)** in the frequency domain in a closed form as

$$\mathbf{[V(x, p)]_{\alpha,\beta,0} = [ch\ \gamma\ x]_{\alpha,\beta,0}\ [V(0, p)]_{\alpha,\beta,0} + [sh\ \gamma\ x]_{\alpha,\beta,0}\ [Z_c]_{\alpha,\beta,0}\ [I\ (0, p)]_{\alpha,\beta,0}}$$

$$\mathbf{[I(x, p)]_{\alpha,\beta,0} = [sh\ \gamma\ x]_{\alpha,\beta,0}\ [Z_c]^{-1}_{\alpha,\beta,0}\ [V(0, p)]_{\alpha,\beta,0} + [ch\ \gamma\ x]_{\alpha,\beta,0}\ [I\ (0, p)]_{\alpha,\beta,0}} \quad (12)$$

Both the supply voltage **E (p)** as well as the supply current $\mathbf{L_{supply}}$ must be introduced in the mathematical analysis using the equation

$$\mathbf{[V\ (0, p)]_{\alpha,\beta,0} = [E\ (p)]_{\alpha,\beta,0} - p\ [L_{supply}]} \quad (13)$$

Consequentially, the voltage **V(x, p)** at a point x of the line may be expressed in wave mode coordinates $[\alpha, \beta, 0]$ by

$$\mathbf{[V(x,p)]_{\alpha,\beta,0} = \{[ch\ \gamma\ (\mathit{l-x}) / \mathit{sh}\ \gamma\ \mathit{l}]_{\alpha,\beta,0}\ [E(p)]\} / \{B\ [Z_c]_\alpha \{[ch\ \gamma\ (\mathit{l-x}) / \mathit{sh}\ \gamma\ \mathit{l}]_\alpha + A\ [Z_c]_\beta \{[ch\ \gamma\ (\mathit{l-x}) / \mathit{sh}\ \gamma\ \mathit{l}]_\beta\ \}} \quad (14)$$

Finally, the voltage of phases $\mathbf{V_{a, b, c}}$ **(x, p)** in phase coordinates **(a, b, c)** will be derived as

$$\mathbf{V_a\ (x, p) = AV_\alpha + B\ V_\beta + (A + B)\ V_0}$$
$$\mathbf{V_b\ (x, p) = A\ B\ (V_\beta - V_\alpha)}$$
$$\mathbf{V_c\ (x, p) = A\ V_\alpha + B\ V_\beta - (A + B)\ V_0} \quad (15)$$

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